DENSITY WAVES IN CROWD ASSEMBLIES: EMERGING PATTERNS AND AGENT BASED MODELING

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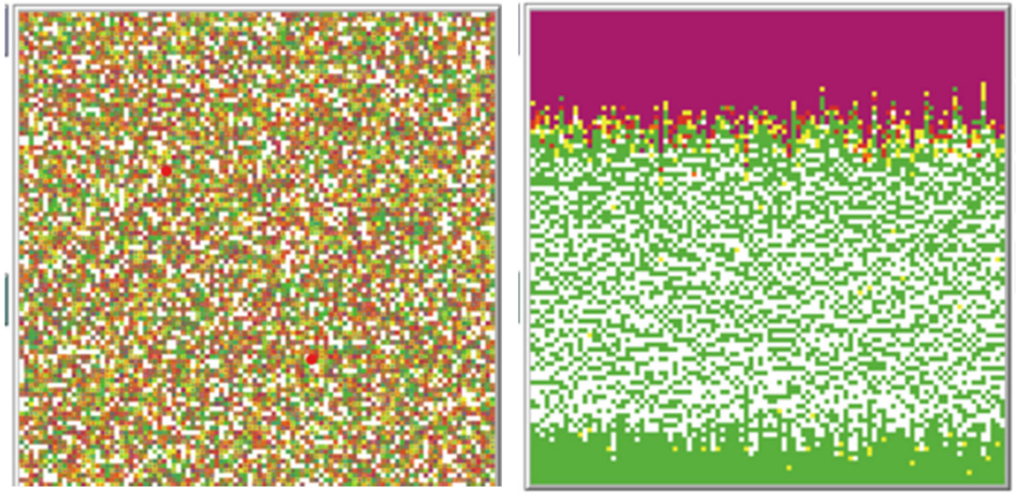
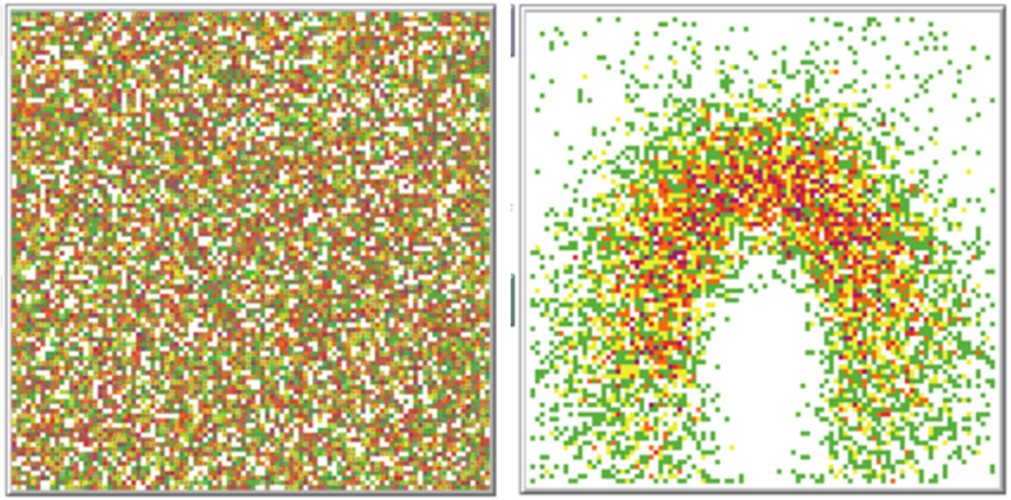
A look at this work



Longitudinal patterns
of the density waves (left)



Radial patterns
of the density waves (right)

Outline

1. **Introduction: Complex Systems and the ODD Protocol**
2. **NetLogo: Behavioral Rules and Constraints**
3. **Simulations: Emerging Patterns**
4. **Conclusions and Future Work**

A look at this work – Introduction: Complex Systems and the ODD Protocol

This study is an update in our research programme for exploring Crowd and Fire Dynamics in their essence of Complex Systems, where the interactions of the single entities in the system may let emerge patterns of behavior of the overall set.

The aim of this study is to explore density waves possibly appearing in crowd assemblies, where some kind of emerging patterns of these waves are expected to appear, starting to depend on initial and boundary conditions.

A modeled crowd of people gathers inside a 2D square domain at the start, with variable initial densities set up to explore different initial conditions.

By the time the movements in the crowd, driven by some event (i.e. reaching some spot for increasing entertainment or for escaping perceived critical situations), significantly vary the density (persons per square meter) from lesser global density values to higher local density values, patterns of pressure waves may start and develop through the assembly.

A look at this work – Introduction: Complex Systems and the ODD Protocol

The behaviors of the people as individual (from reactive to adaptive) define the contact pressures among the persons, where upper thresholds that may be tolerable become critical parameters.

As a consequence, the people's behavior as a whole translates into the pressure density waves propagation.

Suitable metrics and behavioral rules are adopted in order to represent and track the evolution dynamics, where clusters of density and overcrowded situation are hopefully counteracted or avoided by pulses of action helping people recover to better conditions.

To this end, we adopt the Agent Based Modeling (ABM) approach by means of the NetLogo platform, suitable for studying Complex Systems like the one under examination.

The ODD protocol describes the features of our NetLogo model.

NetLogo: a tool suited for studies and research in Complex Systems

A look at this work – Introduction: Complex Systems and the ODD Protocol

The ODD Protocol: Overview, Design concepts, Details.

ODD is a schedule to describe the features of the model in an organised synthetic manner.

The Overview: information is distributed among the agents, with a set of properties describing the initial state of the system and the rules of interaction.

The Design concepts: the model aims at studying basic aspects of this complex system and recognising typical properties.

The Details: initialisation, input data, sub-models.

A look at this work – Introduction: Complex Systems and the ODD Protocol

The ODD Protocol: Overview, Design concepts, Details.

The Overview: The model tries to explore the emergence and the evolution of crowd density waves.

The waves develop while the contact pressure among the persons over a unit area begins to increase and no relief to reduce the pressure is quickly available.

The persons come into contact, ever increasing into a same unit area due to some event, thus shifting toward or remaining inside some area insufficient to collect them at a comfortable level.

The only way to stop pressure from increasing is either limiting the number of persons per unit area or let some persons quickly move away from the overcrowded area, once the event triggers the onset of the wave.

A look at this work – Introduction: Complex Systems and the ODD Protocol

The ODD Protocol: Overview, Design concepts, Details.

The Design concepts: the model aims at studying some basic aspects of this complex system – such as interaction, adaptation, stochasticity – and then characterising some of its typical properties – such as emergence, self-organisation, co-evolution.

We use two NetLogo agentsets: the patches for modeling the world and the turtles for modeling the people.

Depending on the number of persons over a patch, a global density is initialised in the world.

When the number of persons over a patch increases, the patches' colors vary in accordance to let appear the way the density changes, so that local density is also tracked.

The density wave emergence can thus be tracked as the evolution of the colors in the patches.

A look at this work – Introduction: Complex Systems and the ODD Protocol

The ODD Protocol: Overview, Design concepts, Details.

The Details: initialisation, input data, sub-models.

The model is initialised by designing the environment and the agents.

No recorded data are used to start the model, some estimations are made from personal experience and literature survey.

The input data of the environment are the geometry (plan area, side dimensions, perimeter boundaries) and the effects (boundaries closed or open). The input data of the agents are the position (number, spatial distribution) and the characteristics (physical and cognitive).

The sub-models refer to the actions of the agents (movements and decisions), either reactive or adaptive, and to the effects of the environment (perimeter boundaries states).

A look at this work – NetLogo: Behavioral Rules and Constraints

The rules are quite a few, just needed for starting actions and activate reactions or adaptations, with the intent and hope of letting the system evolve by itself to some state with some pattern that may emerge as observable.

What patterns do we mean?

Some kind of pressure density wave patterns due to the contact in the people of the crowd in the environment during the evolution dynamics of the system.

In order to describe the behavioral rules of the agentsets of the system it is convenient to adopt an agent-centric viewpoint.

A look at this work – NetLogo: Behavioral Rules and Constraints

If I am a patch: I help set the world, its domain side, internal area and perimeter boundaries; I am always a 1 m^2 square independently of the domain side chosen, so a suitable metric may be devised; when representing a boundary, my state can be closed or open, and I have an option of adapting my opening to some effect due to the turtles; I can always accept turtles on me; I set and change my color depending on the number of turtles on me, up to a limit threshold.

If I am a turtle: I model a single person; I can move or not move, also changing my heading; I may get closer and closer to other turtles on a same patch, up to a limit threshold of the number of turtles that may be on a same patch in the same time window; if I behave as reactive, my action depends primarily to some event occurred in a past time that may have affected me; if I behave as adaptive, my action depends both on some past event and on some choice or forecast I make to try to get to a better future condition for myself.

A look at this work – NetLogo: Behavioral Rules and Constraints

Once decided the setup (the world with patches and turtles to run the simulation), the model is programmed in such a way to: code the rules, design and apply proper control tools in the NetLogo interface for managing any operation needed and visualizing the results.

The metrics, devised to analyse data, compare results and explain outputs, are based on a continuous space and discrete time frame.

Several runs of a same baseline setup are needed to take into account, at least in a basic form, stochastic effects linked to the system.

Two setups for the model are chosen as representative of this study.

A look at this work – NetLogo: Behavioral Rules and Constraints

The first type of setup is prepared to study the emergence of density waves in the form of longitudinal pressure waves, where the contact among the persons appears along some preferential direction.

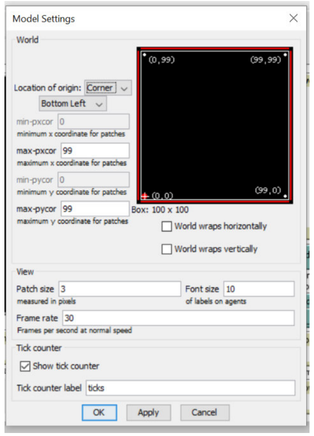
The second type of setup is prepared to study the emergence of density waves in the form of radial pressure waves, where the contact among the persons appears as related to a central spot.

In both cases, the model tries to take into account if some critical parameter that may characterise the response of the system to inputs and noise may appear (i.e. clusters of sudden increased local density, available spots to relieve overpressures, trends of variation in the density).

Furthermore, the model tries to take into account if some threshold marking a sudden onset of changing in the response of the system comes into play (i.e. average local density jump or fall, percentage of dangerous areas in the domain).

A look at this work – NetLogo: Behavioral Rules and Constraints

In order to get started for the model, the NetLogo dashboard interface is properly prepared for this study using many of the specific tools available (some require only an updating to the model to be run, yet some require specific programming). For instance:



the setting of the world (coordinate system, number of patches, state of the perimeter boundaries, time unit advancement);

the dimension of the world (length of the square domain side, area of the domain);

the time unit length of the simulation run (ticks to stop – the tick is the discrete time unit clock: the simulation run advances of one tick whenever all of the agents involved have performed their task);

some monitors to get dynamically variable information during the simulation run (total patches, domain side, total turtles, global density, number of the different colored patches, sum of all patches, average local density, percentage of overcrowded areas);

some 2D-plots that may dynamically vary to show some trend (plots auto-scaling: number of turtles inside the domain over ticks, average densities over ticks as type 1 metric, percentage of overcrowded areas over ticks as type 2 metric).

A look at this work – Simulations: Emerging Patterns

The simulations refer to the study of the emergence of density waves in the form of longitudinal pressure waves and in the form of radial pressure waves. Two types of setup are prepared in consequence, sharing similarities and differences.

Similiarities of the two types of setup:

initialisation of the world (100 m side length square domain, perimeter boundaries closed, 100 x 100 square patches 1 m side 1 m^2 each, random sprouting of turtles per patches with random headings, two global densities possible of 2 and 1 persons per square meter, colors of patches depending on the local density of turtles per patch); tools on the dashboard interface (monitors and plots), metrics (average local density, up to a limit that will stop the simulation; percentage of overcrowded areas), runtime clock (ticks to end of simulation), updating during run (colors of patches, data on monitors and plots), intention of actions (move, recover).

Differences of the two types of setup:

patterns of simulation (form-clusters, move-clusters) and some behavioral rules (patches, turtles).

A look at this work – Simulations: Emerging Patterns

Longitudinal patterns - Behavioral rules for actions

Longitudinal Waves Emerging Patterns		
Action	*Agentset*	*Behavior*
Setting the world	Patches	Initialisation of the geometry, sprouting of the turtles, local density mapping
To move	Turtles	First half of simulation runtime window – Set of heading, wiggle and move forward or stop
To recover	Turtles	Second half of simulation runtime window – Reverse of heading, wiggle and move forward or stop
Density wave rendering	Patches	Updating local density mapping

Radial patterns - Behavioral rules for actions

Radial Waves Emerging Patterns		
Action	*Agentset*	*Behavior*
Setting the world	Patches	Initialisation of the geometry, sprouting of the turtles, local density mapping
To form-clusters	Turtles	First half of simulation runtime window – Set of heading, wiggle and move forward or stop
To move-clusters	Turtles	Second half of simulation runtime – Reverse of heading, wait, wiggle and move forward or stop
Density wave rendering	Patches	Updating local density mapping
Escape from the world	Patches	Updating local density mapping
Escape from the world	Turtles	Check of patches and local density threshold, die

A look at this work – Simulations: Emerging Patterns

For both types of emerging patterns, longitudinal and radial, several simulations are performed based on these actions and rules.

Groups of four simulations are used, each based on a similar initial setup but with four different runtime windows of 100, 300, 500 and 1000 ticks, and global density on average of 2 p/m^2 or 1 p/m^2.

Some slight differences appear for each group in the initial setups and in the results, due to the random actions coded (i.e. sprouting of turtles) and the overall evolution dynamics.

Any of these related four simulations show how the emerging patterns of the density waves may vary, starting from substantially similar conditions, depending on the effects on the system of the single actions performed by the agents involved in function of the runtime clock available.

A look at this work – Simulations: Emerging Patterns

Here follow some results obtained from the simulations.

The results are shown in a same way, where each related figure shows:

the 2D-domain at the end of the runtime elapsed,

the metric of the average densities,

the metric of the overcrowded areas.

The colors in the domain represent the color of the patches, mapping the local densities updated along the run, where:

white patches have 0 turtles on, green patches have 1 turtle on, yellow patches have 2 turtles on, orange patches have 3 turtles on, red patches have 4 turtles on, magenta patches have > 4 turtles on up to a limit that can be varied to study different conditions.

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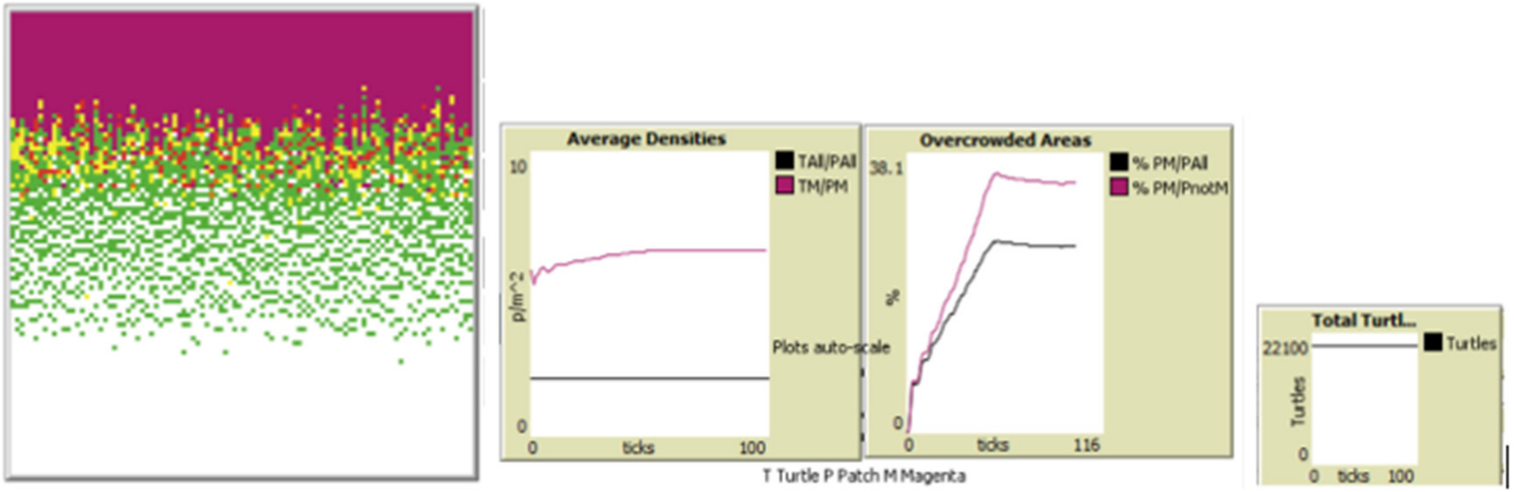
A look at this work – Simulations: Emerging Patterns

Longitudinal Waves Emerging Patterns

0 p/m²
1 p/m²
2 p/m²
3 p/m²
4 p/m²
>4 p/m²



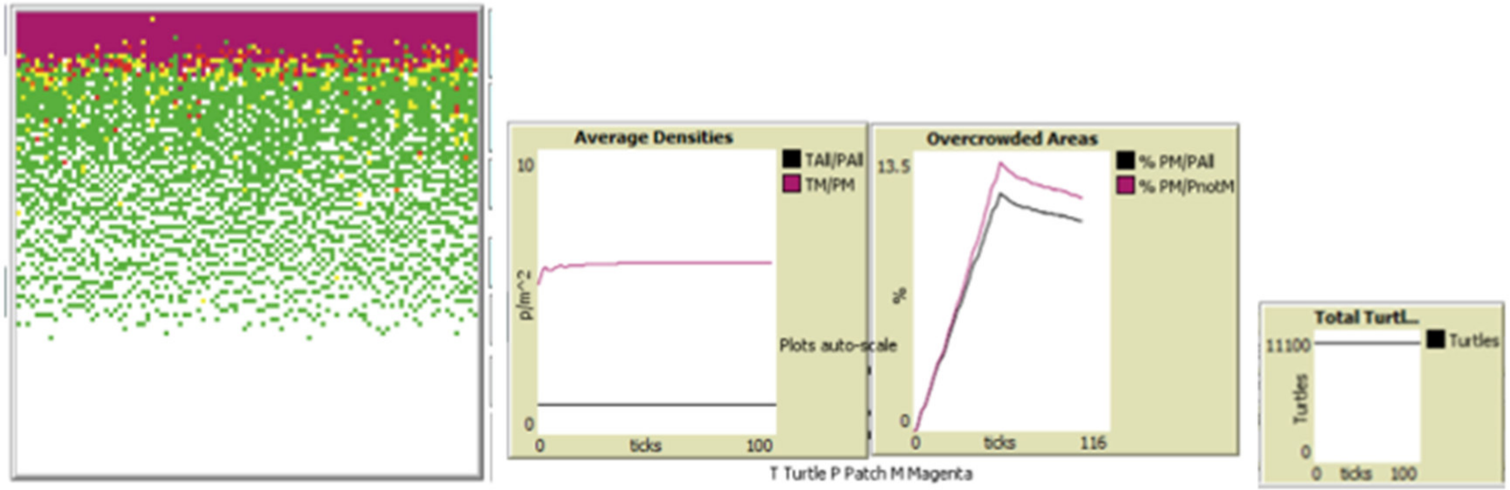
Initial global density of 2 p/m^2 with 20000 persons in the 100 m side square domain with boundaries closed

Simulation at 100 ticks end of run completed

A look at this work – Simulations: Emerging Patterns

Longitudinal Waves Emerging Patterns

0 p/m²
1 p/m²
2 p/m²
3 p/m²
4 p/m²
>4 p/m²



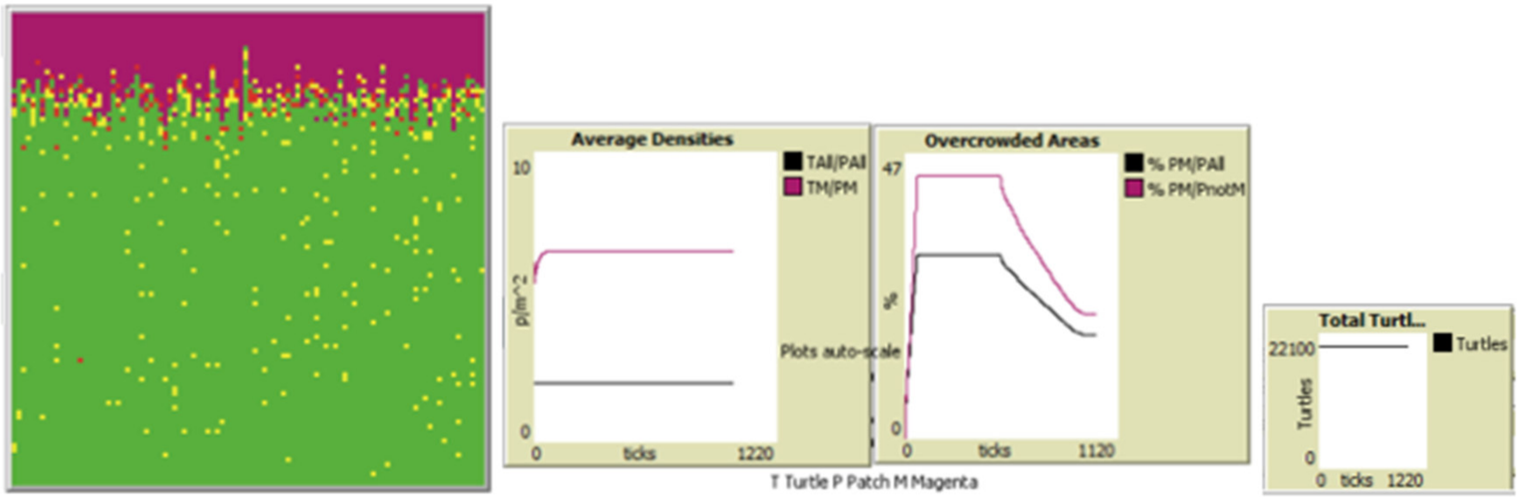
Initial global density of 1 p/m ^{2} with 10000 persons in the 100 m side square domain with boundaries closed

Simulation at 100 ticks end of run completed

A look at this work – Simulations: Emerging Patterns

Longitudinal Waves Emerging Patterns

- 0 p/m²
- 1 p/m²
- 2 p/m²
- 3 p/m²
- 4 p/m²
- >4 p/m²



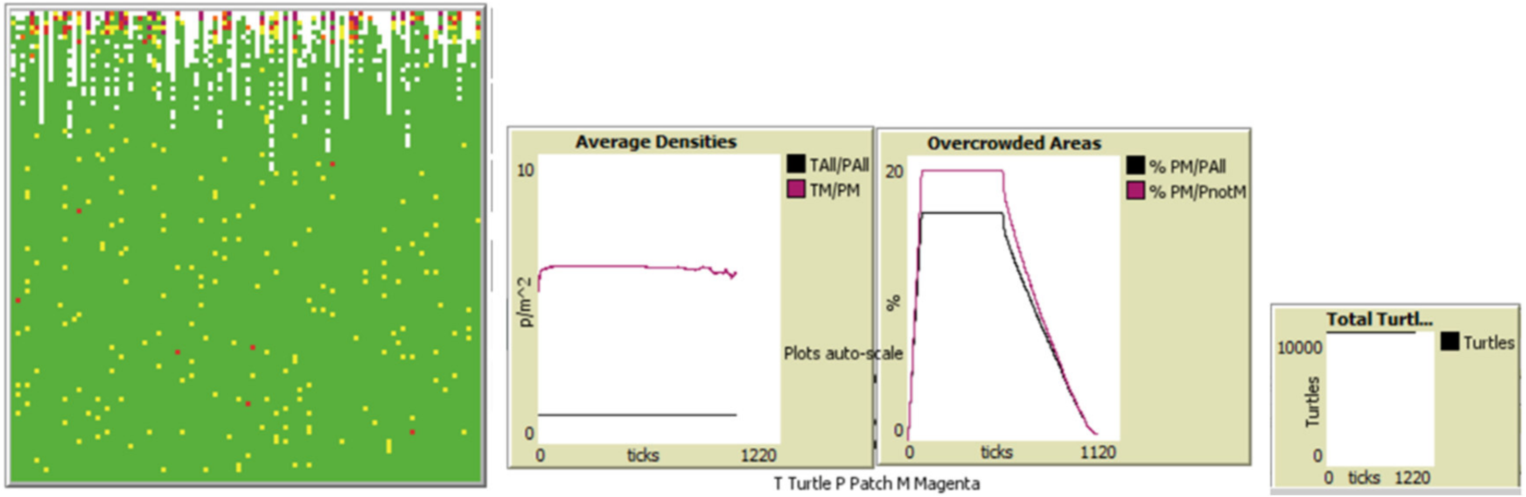
Initial global density of 2 p/m ^{2} with 20000 persons in the 100 m side square domain with boundaries closed

Simulation at 1000 ticks end of run completed

A look at this work – Simulations: Emerging Patterns

Longitudinal Waves Emerging Patterns

- 0 p/m²
- 1 p/m²
- 2 p/m²
- 3 p/m²
- 4 p/m²
- >4 p/m²



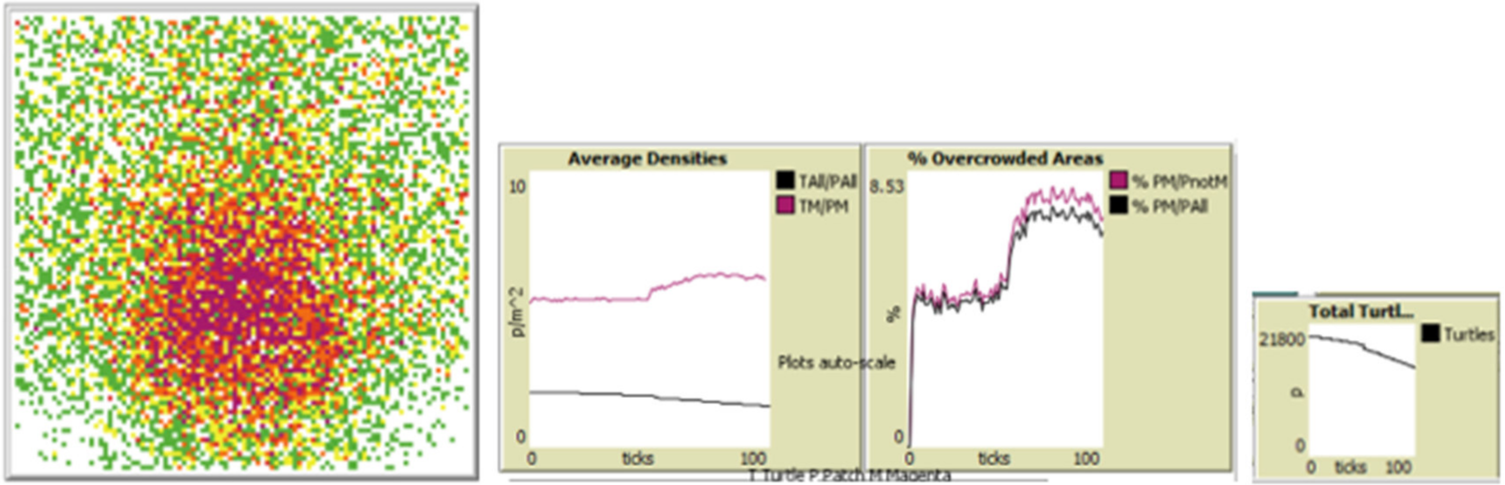
Initial global density of 1 p/m ^{2} with 10000 persons in the 100 m side square domain with boundaries closed

Simulation at 1000 ticks end of run completed

A look at this work – Simulations: Emerging Patterns

Radial Waves Emerging Patterns

0 p/m²
1 p/m²
2 p/m²
3 p/m²
4 p/m²
>4 p/m²



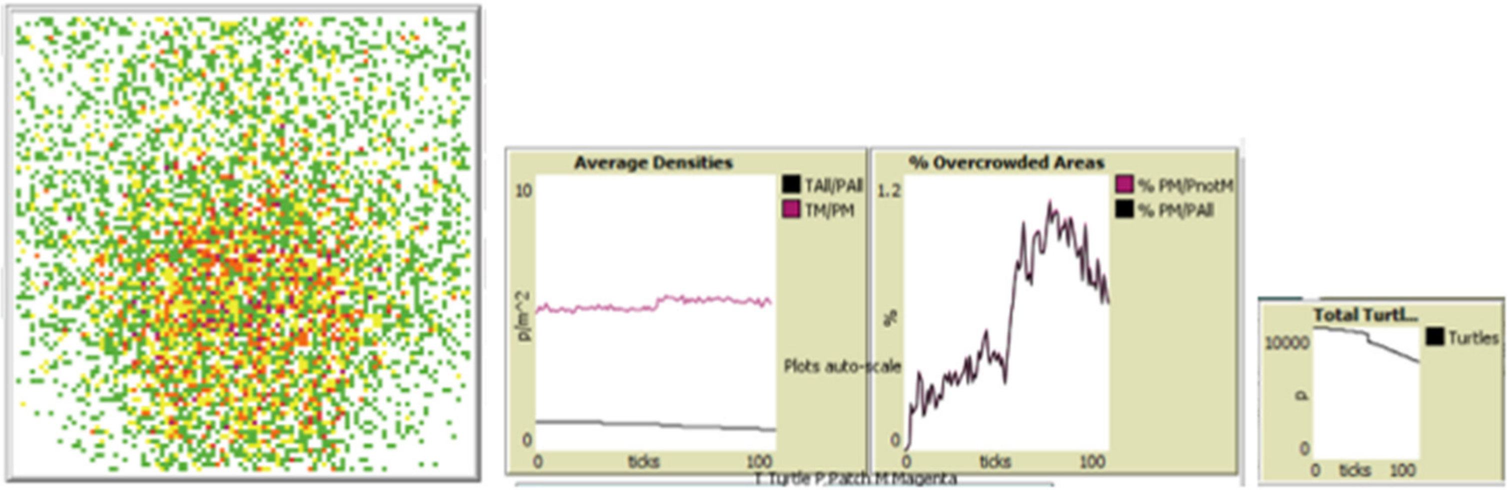
Initial global density of 2 p/m^2 with 20000 persons in the 100 m side square domain with adaptive boundaries
4 p/m^2 limit threshold at boundary

Simulation at 100 ticks end of run completed

A look at this work – Simulations: Emerging Patterns

Radial Waves Emerging Patterns

0 p/m²
1 p/m²
2 p/m²
3 p/m²
4 p/m²
>4 p/m²



Initial global density of 1 p/m^2 with 10000 persons in the 100 m side square domain with adaptive boundaries
4 p/m^2 limit threshold at boundary

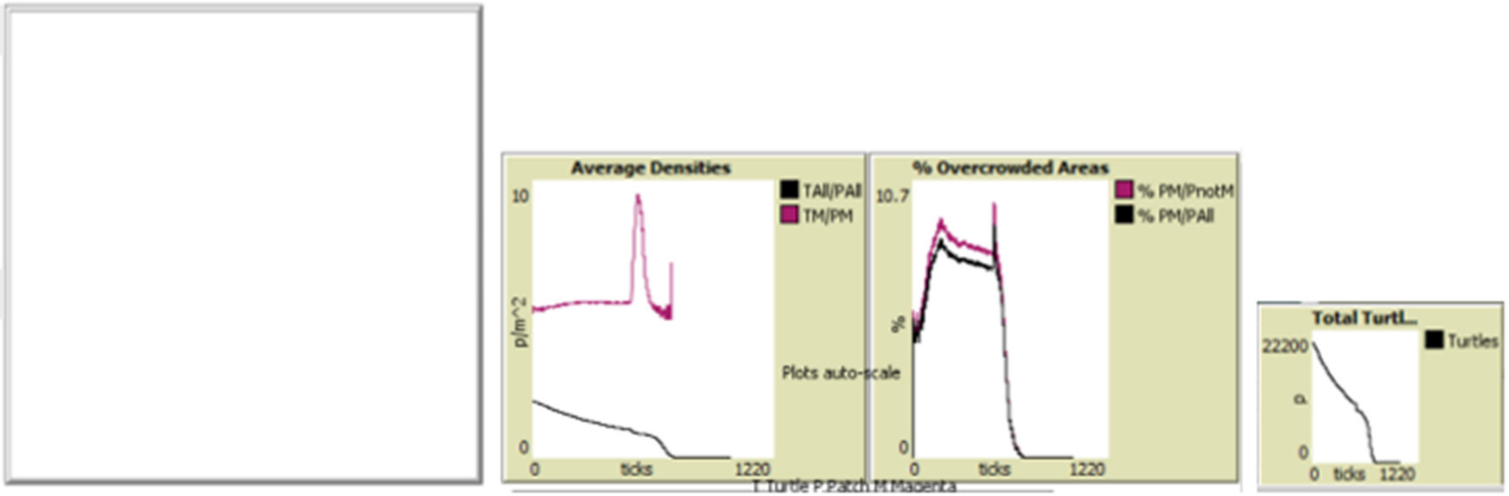
Simulation at 100 ticks end of run completed

3

A look at this work – Simulations: Emerging Patterns

Radial Waves Emerging Patterns

0 p/m^2
1 p/m^2
2 p/m^2
3 p/m^2
4 p/m^2
>4 p/m^2



Initial global density of 2 p/m^2 with 20000 persons in the 100 m side square domain with adaptive boundaries
4 p/m^2 limit threshold at boundary

Simulation at 1000 ticks end of run completed

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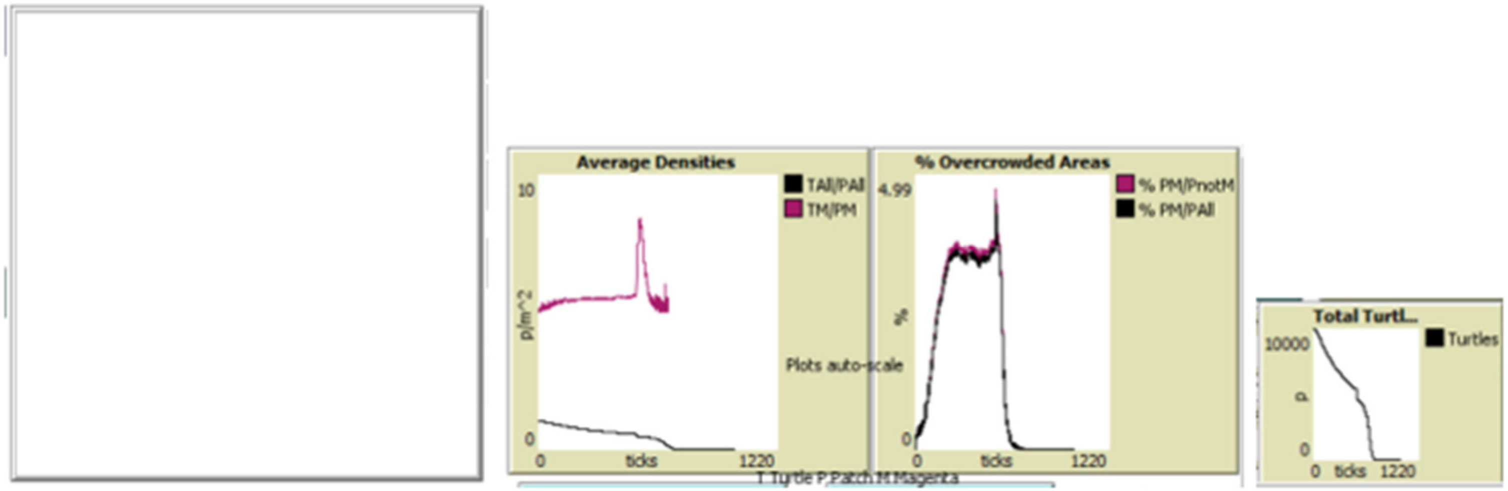
A look at this work – Simulations: Emerging Patterns

Radial Waves Emerging Patterns

- 0 p/m^2
- 1 p/m^2
- 2 p/m^2
- 3 p/m^2
- 4 p/m^2
- >4 p/m^2



Initial global density of 1 p/m^2 with 10000 persons in the 100 m side square domain with adaptive boundaries 4 p/m^2 limit threshold at boundary

Simulation at 1000 ticks end of run completed

A look at this work – Simulations: Emerging Patterns

Here follow some other results obtained from the simulations, referred to both longitudinal and radial wave patterns.

In order to show some shape of the evolution dynamics of the emerging patterns, the results are shown at a sequence of the time advancement of the runtime elapsed for the simulations, with the runtime window of 1000 ticks, and global density on average of 2 p/m^2 or 1 p/m^2.

The colors in the domain represent the color of the patches, mapping the local densities updated along the run, where:

> white patches have 0 turtles on, green patches have 1 turtle on, yellow patches have 2 turtles on, orange patches have 3 turtles on, red patches have 4 turtles on, magenta patches have > 4 turtles on up to a limit that can be varied to study different conditions.

A look at this work – Simulations: Emerging Patterns

Longitudinal Waves Emerging Patterns

0 p/m²
1 p/m²
2 p/m²
3 p/m²
4 p/m²
>4 p/m²

Initial global density of 2 p/m^2 with 20000 persons in the 100 m side square domain with boundaries closed

Simulation at ticks 0 (start), 25, 499, 700, 1000 (end of run completed)

A look at this work – Simulations: Emerging Patterns

Longitudinal Waves Emerging Patterns

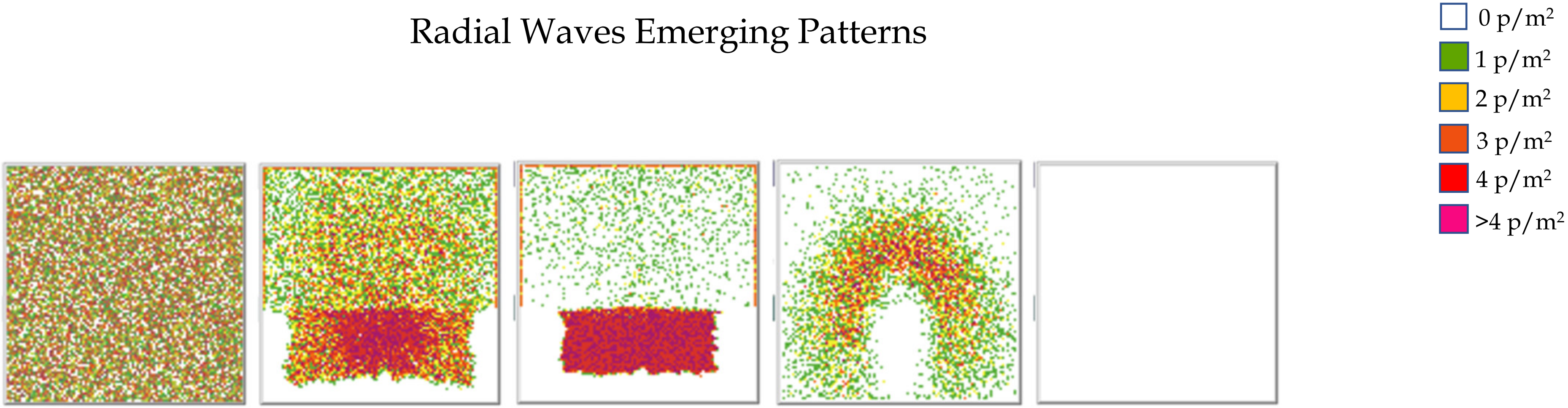
- 0 p/m^2
- 1 p/m^2
- 2 p/m^2
- 3 p/m^2
- 4 p/m^2
- >4 p/m^2

Initial global density of 1 p/m^2 with 10000 persons in the 100 m side square domain with boundaries closed

Simulation at ticks 0 (start), 25, 499, 700, 1000 (end of run completed)

A look at this work – Simulations: Emerging Patterns

Radial Waves Emerging Patterns



Initial global density of 2 p/m^2 with 20000 persons in the 100 m side square domain with adaptive boundaries
4 p/m^2 limit threshold at boundary

Simulation at ticks 0 (start), 100, 499, 600, 1000 (end of run completed)

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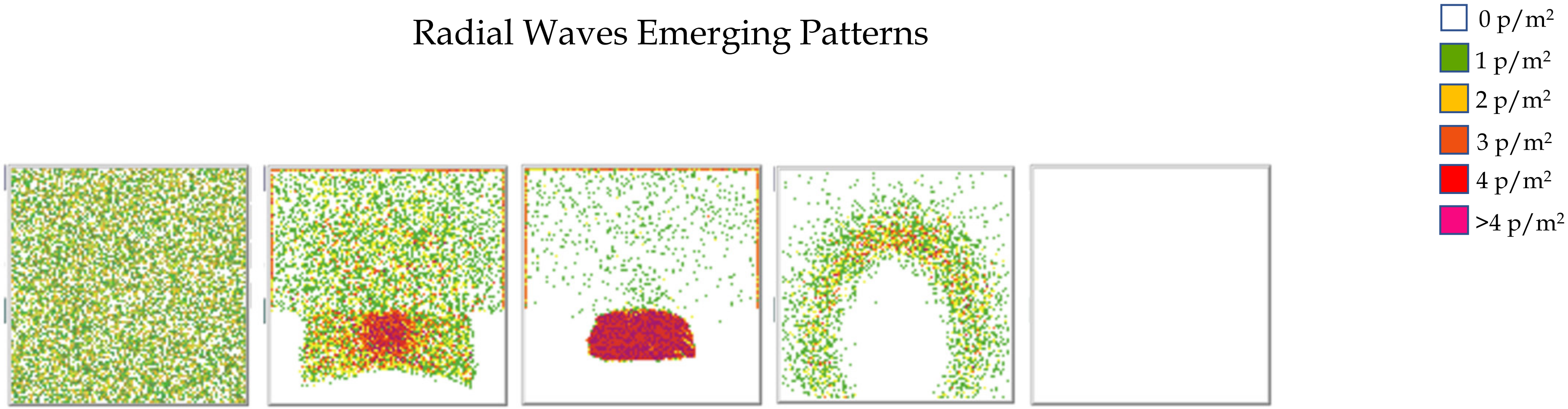
A look at this work – Simulations: Emerging Patterns

Radial Waves Emerging Patterns



Initial global density of 1 p/m^2 with 10000 persons in the 100 m side square domain with adaptive boundaries
4 p/m^2 limit threshold at boundary

Simulation at ticks 0 (start), 100, 499, 600, 1000 (end of run completed)

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A look at this work – Conclusion and Future Work

The model was able to let patterns emerge in all of the simulations, with characteristics of development depending on the initial setup and the interactions in the system during the runtime.

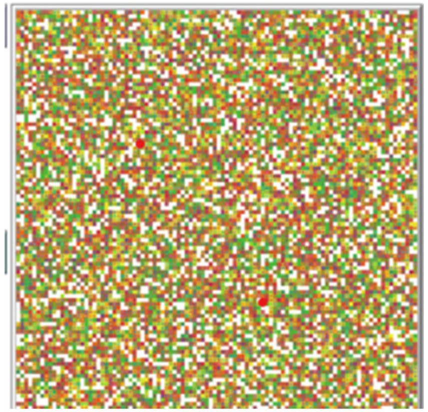
Some parameters show a greater effect on the results than others. In particular:

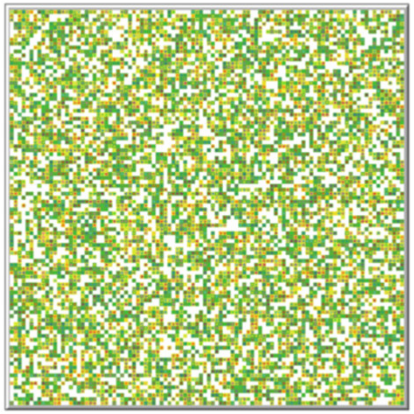
- the initial global density,
- the time the boundaries can get opened,
- the limit average density threshold.

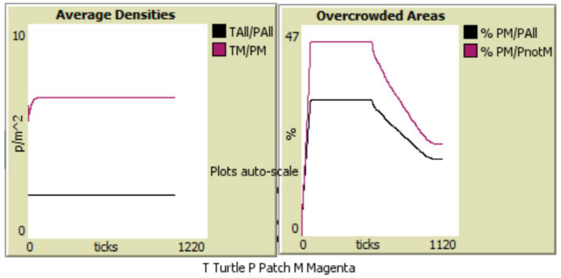
The metrics show overall trends and sudden changes in the evolution dynamics of the system.

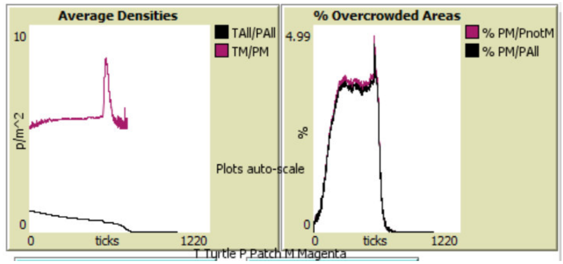
A look at this work – Conclusion and Future Work

Future work is scheduled to expand the groups of simulations and examine in detail similarities and differences, and to examine the effect of critical parameters as input (i.e. initial density, boundaries opening, density threshold) and output (i.e. metrics).









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Thank you

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